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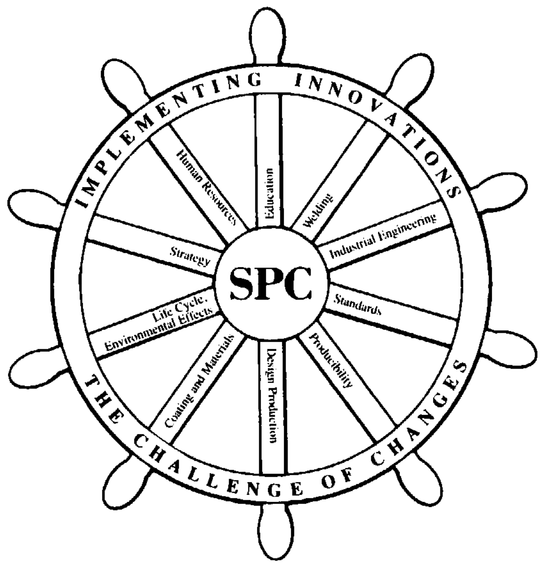

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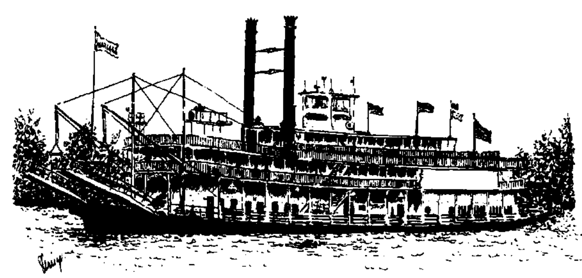

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Strip Cladding of Main Propeller Shafting with Ni Alloy 625 by Electroslap Surfacing

No. 7C-2

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ABSTRACT

A comprehensive comparison between electroslag surfacing (ESS) and submerged arc surfacing (SAS) using 30 mm (1.2 inch) wide x 0.5 mm (0.020 inch) thick Ni Alloy 625 strip was conducted in both the as-deposited and stress relieved (at 604°C, 1120°F) conditions. In most cases, exactly duplicate cladding conditions were used to best compare ESS with SAS. Ni Alloy 625 strip was deposited on 10 cm (4 inch) thick flat plates and 64 cm (25 inch) diameter shafting (both MIL-S-23284 Class 1 steel) using optimized ESS and SAS processes. Tensile, CVN toughness, and face and side bend tests were performed on as-welded and stress-relieved cladding at room temperature. Microstructural analyses of the clad specimens were performed using optical and electron microscopy.

Cladding parameters were found to affect the dilution, deposition rate, and penetration. Although ESS and SAS cladding possessed similar strength levels, the cladding deposited by ESS was shown to have greater ductility than that by SAS. Also, the resistance to solidification cracking of cladding by ESS was superior to SAS because of the reduced Si, C, 0, and impurity levels which promote interdendritic Laves phase, Nb-rich MC carbides and inclusions. Compared to SAS, the ESS method proved to be not only more metallurgically favorable but also cost-effective.

The mechanical properties, solidification cracking resistance and microstructure of electroslag cladding deposited with (1) Ni Alloy 625, (2) modified Ni Alloy 625 with low iron and (3) Ni Alloy 59 were compared. These Ni alloy strips produced cladding deposited on Class 1 steel with nearly similar mechanical properties. Cladding deposited with Ni Alloy 59 strip developed the best resistance to solidification cracking due to its very low Nb content which was found to reduce the level of detrimental Laves phase in the cladding microstructure.

Due to the high carbon content and high hardenability of the shafting steel, an appropriate preheating had to be determined. Y-groove testing, diffusible hydrogen testing and microstructural analysis was used to establish a safe preheating temperature.

INTRODUCTION

Electroslag surfacing (ESS) with strip electrodes is a new cladding technology in the USA. Until recently, high deposition rate cladding was performed exclusively by the submerged arc surfacing (SAS) process. But previous work has shown that ESS could produce about twice the deposition rate with half the dilution and less than half the impurity inclusion content compared to SAS. As a result, a program sponsored by the Navy ManTech-Office was initiated in 1990 to clad Ni Alloy 625 on-to main propulsion shafting.

In 1971, Seidel and Hess (1) reported a new adaptation of electroslag processing for cladding in the flat position using strip electrodes and called it electroslag surfacing. Ten years later, this concept was also utilized by Nakano et al(2) in Japan to develop Kawasaki's electroslag surfacing techniaue called "Maqlay." Since that time, many technical-papers have been published on electroslag surfacing in the flat position (3-12).

The great advantage of electroslag surfacing is high deposition rate, low dilution and cost-effectiveness. The electroslag surfacing process with strip electrodes has been shown to generate a substantially greater deposition rate with much less-dilution compared to its nearest competitor. submeraed arc strip surfacing (6). Because of-the high CaF content in the flux, cladding deposited' by electroslag surfacing contains about one third the oxygen content compared to submerged arc surfacing.

The objective of this research was to compare the cladding characteristics and capabilities of the electroslag

surfacing and the conventional submerged arc surfacing of MIL-S-23284, Class 1 steel with Ni Alloy 625 strip. These characteristics included deposition rate, penetration, dilution, cladding composition, microstructure and mechanical properties. A second objective was to compare the properties and microstructure of electroslag cladding deposited with three strip compositions: (1) conventional Ni Alloy 625, (2) Ni Alloy 625 with low iron and (3) Ni Alloy 59. The third objective was to determine the safe preheating temperature for this new ESS process.

EXPERIMENTAL PROCEDURE

The materials in this study included 100 mm (4 inch) thick plate of MIL-S-23284, Class 1 steel. The filler strip electrodes were 30 mm (1.2 inch) by 0.5 mm (0.020 inch) thick and consisted of Ni Alloy 625, modified Ni Alloy 625 with low Fe and Alloy 59. Compositions of materials are given in Table I. The flux compositions for both ESS and SAS are

TABLE I. Composition of Shafting Steel (MIL-S-23284, Class 1) and 30 X 0.5 mm Strip Electrodes

		Strip Electrodes		
	Shaft	Alloy 625	Alloy 625 (LOW Fe)	Alloy 59
C	0.25	0.03	0.005	0.007
Fe	BAL	4.25	0.95	0.34
Si	0.22	0.09	0.04	0.04
MO	0.44	9.00	9.30	15.5
Nb		3.45	3.70	0.30
Cr	0.42	21.50	22.50	22.50
Mn	0.34	0.00	0.03	0.15
Ni	3.25	BAL	BAL	BAL
Ti			0.2	

presented in Table II. Cladding to compare ESS with SAS involved duplicate welding conditions using the same constant voltage DCep power supply. The flux was baked to at least 94°C (200°F) before cladding.

TABLE II. Major Ingredients in the Flux Used for ESS and SAS

	ESS	SAS
CaF_2	80	16
CaO		24
SiO_2	5	25
Al_2O_3	8	29

Microscopic examination of cladding included optical microscopy, scanning electron microscopy and scanning-transmission electron microscopy (STEM).

The etchant used for optical microscopy of the cladding was electrolytic oxalic acid. The steel base metal was etched in 1% nital. The dilution measurements and profile of the bead and HAZ were calculated by an image analyzer. The dilution is defined as:

$$\%Dilution=\frac{B}{B+A}$$

where A is the transverse cross sectional area of the cladding reinforcement above the base metal surface and B is the cross sectional area of the melted base metal below the base metal surface.

Mechanical testing of the cladding included tensile testing and bend testing. In all cases, tensile specimens were machined so that the longitudinal direction of the tensile specimens was always perpendicular to the direction of cladding. For single 0layer cladding approximately 6 mm (l/4 inch) thick, flat all-cladding tensile specimens were used and tested in accordance with ASTM E8. For the multilayer cladding approxi- mately 25 mm (1 inch) thick, 12.7 mm (1/2 inch) diameter all-cladding round tensile specimens were used. In bend testing, only single layer tests were conducted in accordance with the guided bend test procedure in AWS B4.0. Both side and face bend specimens were machined so that the longitudinal axes of the bend specimens were always perpendicular to the cladding direction.

A new solidification cracking was designed particularly for cladding with strip electrodes as illustrated in Figure 1. In this test, a non-symmetrical slit 1.75 mm (0.07 inch) was placed in the center of a 25 mm thick plate of the MIL-S-23284, Class 1 steel. In Figure 1, "L", is the total crack length measured across the width of the strip cladding bead and "W" is the bead width.

RESULTS & DISCUSSION

Cladding Variables

In comparing electroslag surfacing (ESS) with submerged arc surfacing (SAS) the welding variables such-as current, voltage and travel speed affected deposition and dilution. Raising current (Figure 2) increased deposition rate significantly but only slightly decreased dilution. Increasing travel speed (Figure 3) had little effect on deposition rate while greatly increasing dilution. Since voltage changes (Figure 4) had little effect on deposition rate and dilution, voltage was used to control the bead shape of

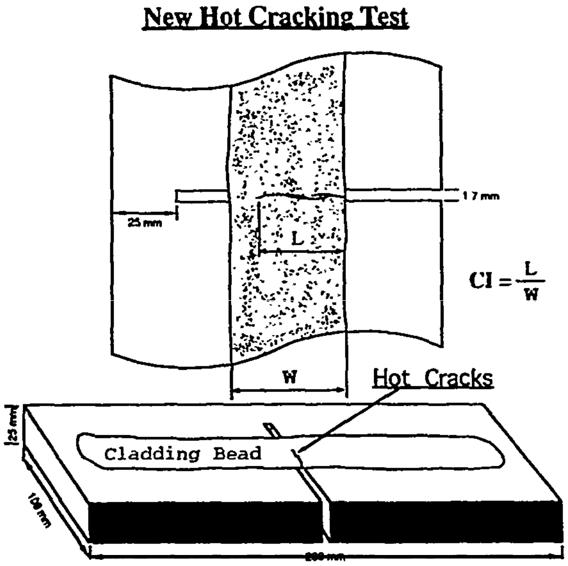

FIGURE 1. Solidification Cracking Test for Strip Cladding Developed by Oregon Graduate Institute.

the cladding. When comparing similar cladding deposited by ESS versus SAS (for reference) using the same welding variables, the ESS process developed a greater deposition rate and lower dilution than similar cladding deposited by SAS. After analyzing the effects of cladding variables, the optimized parameters for ESS were develop to provide excellent cladding integrity with minimal (6% - 8%) dilution for Ni Alloy 625 strip deposited on steel as shown in Table III.

Tensile Testing

ESS and SAS cladding layers were deposited on the MIL-S-23284, Class 1 steel for mechanical testing. The tensile tests were carried out on single layers of the Ni alloy 625 cladding approximately 6 mm (0.23 inch) thick in both the as-clad and stress-relieved conditions using the parameters shown in Table III. The yield strengths of both ESS and SAS cladding were similar but the cladding deposited by ESS possessed substantially higher ductility than did comparable cladding deposited by SAS as shown in Table IV. Also, the ductility in the as-welded condition was generally higher than the stress relieved cladding for both ESS and SAS.

A similar comparison of the tensile properties of multiple layers of cladding approximately 25 mm (1 inch) thick deposited by ESS was conducted. Cladding deposited by ESS using Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59, and cladding by SAS with Ni Alloy 625 (for reference) in both the as-clad and stress-relieved conditions are

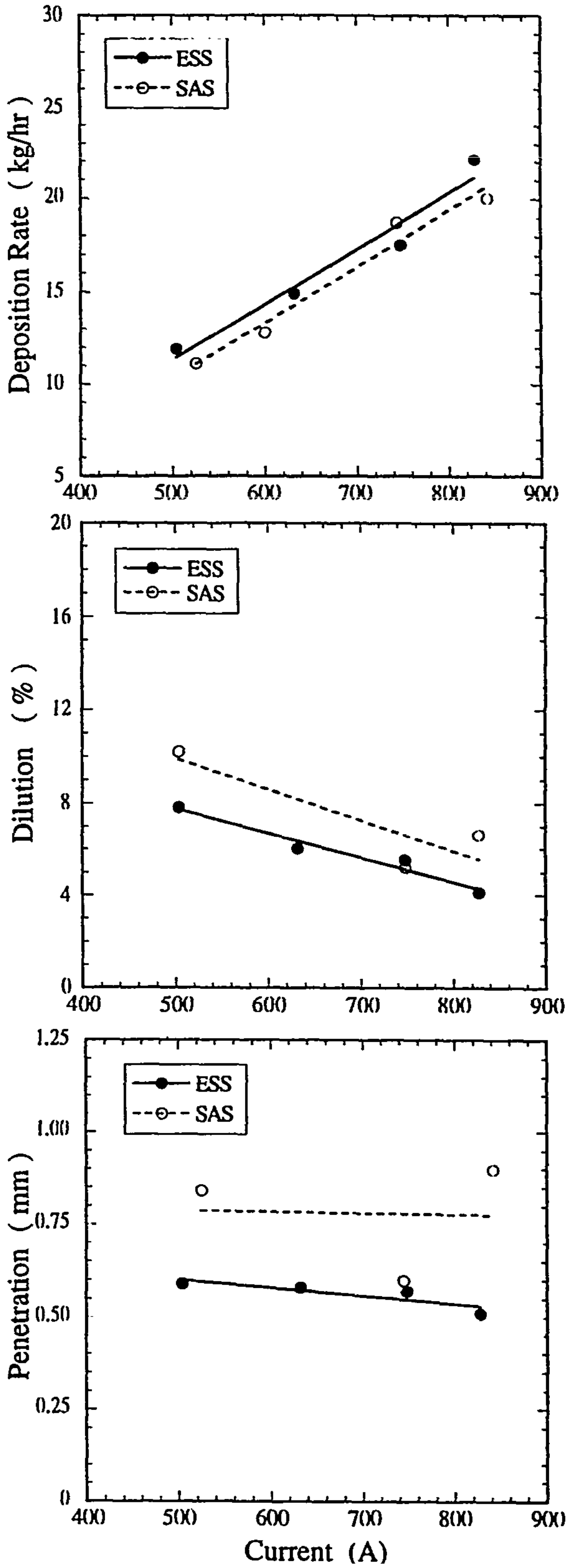

FIGURE 2. The Effect of Current on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

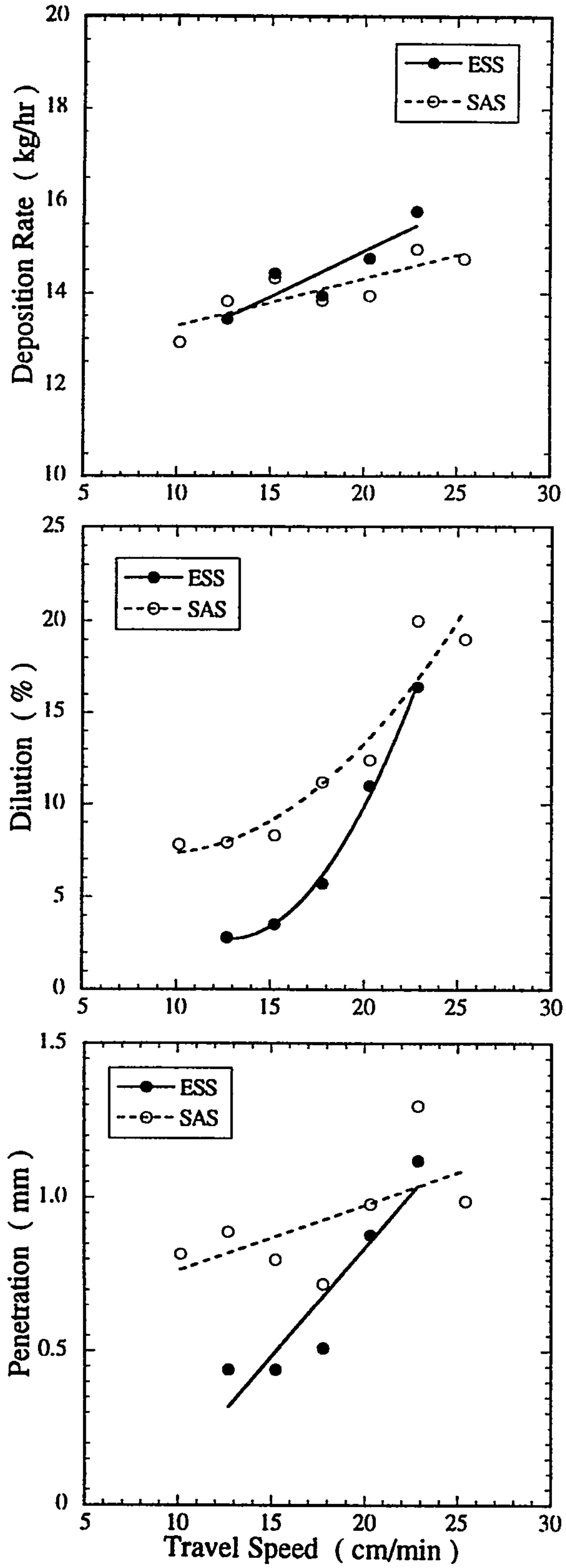

FIGURE 3. The Effect of Travel speed on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

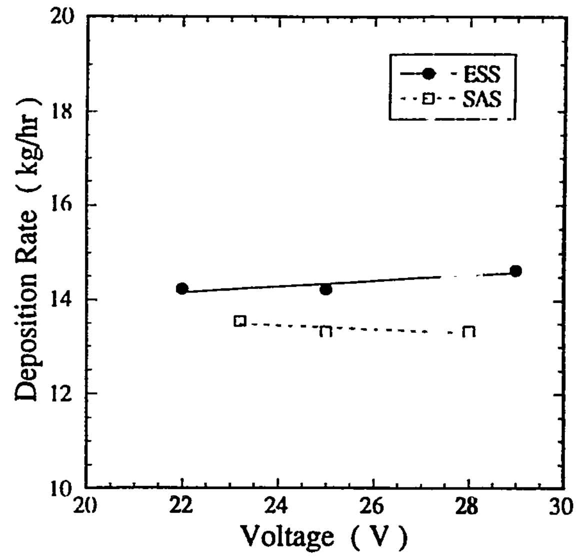

FIGURE 4. The Effect of Voltage on the Deposition Rate, Dilution and Penetration of Cladding Deposited on MIL-S-23284 Class 1 Steel Using 30 by 0.5 mm Strip of Ni Alloy 625.

compared in Figure 5. Generally, the strength and ductility of cladding deposited with Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59 strips were similar. The ductility values were all superior to that of the parent shafting steel. Stress relief heat treatment of the cladding at 604OC (1120°F) produced no observable change in mechanical properties.

Rend Testing

The side and face bend tests were carried out on single layers of the Ni alloy 625 cladding approximately 6 mm (0.23 inch) thick (deposited on MIL-S-23284 Class 1 steel) in both the as-clad and stress-relieved conditions as shown in Table V. All face bend and side bend specimens containing both the cladding deposited by ESS and SAS passed the 22% strain level of MIL-S-23284 Class 1 base metal. Also in Table V, the face and side bend tests results of ESS cladding deposited with Ni Alloy 625, low-Fe Ni Alloy 625 and Ni Alloy 59 are presented. In all cases, each type of Ni alloy strip produced ductile cladding which passed the 22% elongation face and side bend tests without any sign of surface cracking or defects.

TABLE III. Variables for Electroslag Cladding MIL-S-23284. Classes 1 Steel Shafting Using 30 X 0.5 mm Ni Alloy 625 Strip

STRIP FEED SPEED	185 CM/MIN 73 IN/MIN	+/- 13 +/- 5
CURRENT	650 A (TYPICAL*)	
VOLTAGE	27 V	+/- 1
MACHINE TYPE	DCep CONSTANT VOLTAGE	
TRAVEL SPEED	178 MM/MIN 7 IPM	160/190 6.5/7.5
TIE-IN OVERLAP	4 MM 0.160 IN	3.5-5.0 .140/.200
WELD HEAD POSITION	7° DOWNHILL	+/- 1
STRIP FEED ANGLE	7°	+/- 1
FLUX	59s (SANDVIK OR SOUDOMETAL)	
WELDING HEAD	HEAVY DUTY; WATER-COOLED	
PREHEATING TEMPERATURE	200°C (400°F) MIN	
INTERPASS TEMPERATURE	315°c (600°F) MAX	
POST SURFACING STRESS RELIEF	650°C 1200°F	+/- 15 +/- 25

* Only typical values of current are given because current is dependent upon strip feed speed.

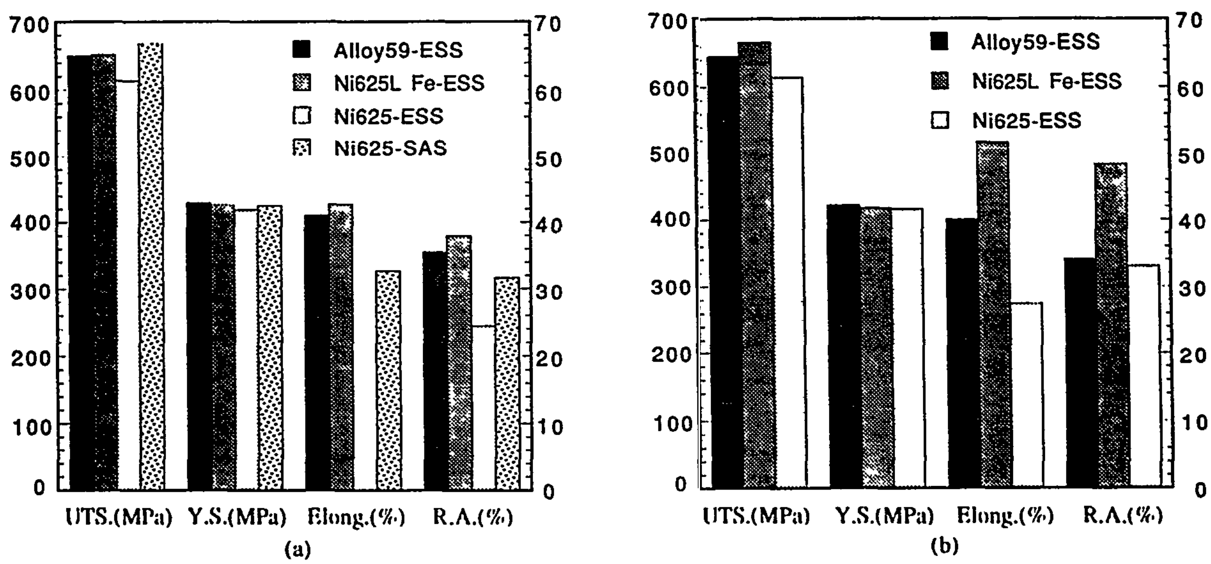

FIGURE 5. Tensile Properties of 25 mm (1 inch) Thick Cladding Deposited in Five Layers with Ni Alloy Strips on MIL-S-23294, Class 1 Steel Using ESS; (a) As-welded and (b) Post-weld Stress Relieved.

TABLE IV. Tensile Properties of NI Alloy 625 Cladding Deposited in a Single Layer on MIL-S-23294, Class 1 Steel Using ESS and SAS

	YS. MPa	UTS. MPa	%ELONG	%RA
Base Metal	617	754	21	62.5
Ni 625 Strip	490	855	50	
AS-CLAD CONDITION				
ESS	393	676	50	38.5
SAS	386	669	39	38.5
STRESS RELIEVED AT 604°C (1120°F)				
ESS	407	696	42	38
SAS	379	676	32	31

TABLE V. Face and Side Bend Test of Cladded Plate per AWS B4.0 to Pass 22% Strain Required by MIL-S-23284 Class 1

	E S S	S A S
Ni Alloy 625	pass	pass
625 with Low Fe	pass	N/A
Ni Alloy 59	pass	N/A

Solidification Crackina Susceptibility

Although many solidification cracking tests have been developed for weld metal deposits, none were found acceptable for testing of strip cladding. The new Oregon Graduate Institute design for a solidification cracking test for strip cladding is shown in Figure 1. This test was applied to both ESS and SAS cladding using different strip electrode compositions including 309L stainless steel containing 9% ferrite and 7O%Cu-300Ni for reference. The 309L is known to be crack resistant whereas the 7O%Cu-30%Ni strip deposited on steel is known to be extremely susceptible to solidification cracking and should always fail the OGI cracking test. The results of this strip cladding test are given in Table VI.

From Table VI, the Ni alloys appear to be more susceptible to solidification cracking than the 309L austenitic stainless steel as expected. However, the cladding deposited by SAS was more sensitive to solidification cracking than similar cladding deposited by ESS. The reason for the increased cracking susceptibility in cladding by SAS may be due to two factors: (1) the slag reaction that raises the Si content of cladding to enhance formation of the low melting interdendritic Laves phase, and (2) the high level of dilution from the steel base metal that is characteristic of SAS. The differences in solidification cracking susceptibility for cladding deposited by ESS using Ni Alloy 625, modified low Fe 625 and Ni Alloy 59 were small. Table VI, shows that Ni Alloy 59 probably possessed the best resistance to solidification cracking.

Composition Profile of Cladding

The composition of the cladding was found to be dependent upon (1) dilution from the MIL-S-23284, Class 1 steel base metal, (2) slag reactions, and (3) distance from the base metal interface. In Figure 6, the chemical compositions of the lst, 2nd, 3rd and 4th layers of cladding are given for both ESS and SAS deposits. In Figure 6a, the carbon content was lower than that in either the strip or base metal due to a slag reaction. Because of the lower dilution from ESS compared to SAS, Fe contents of the first layer of the electroslag deposits using Ni Alloy 625, modified low Fe 625 and Ni Alloy 59 were well below the 9% limit specified by NAVSEA 0900-LP-014-1010. The cladding deposited by SAS, however, exceeded the 9% limit in the first layer. The extra low Fe contents of the Ni Alloy 59 strip and Ni Alloy 625 with low Fe strir, tended to also reduce the iron content of the first layer cladding deposited on steel shafting. The Fe contents in the 2nd, 3rd, and 4th layers of both ESS and SAS cladding were below 9% as shown in Figure 6b. In Figure 6c, the Si content of cladding deposited by SAS was nearly 4 times greater than that in the ESS cladding. This is due to the high SiO content in the SAS flux. High Si leve1s may have increased solidification crack sensitivity in the SAS cladding as shown in Table VI.

TABLE VI. Oregon Graduate Institute Solidification Cracking Test of Strip Cladding Deposited on MIL-S-23284 Class 1 Steel

	309L SS	Ni Alloy 625	Ni Alloy 625 (LOW Iron)	Ni Alloy 59	70Cu-Ni
ESS	0	l/3	l/4	1/8	1
SAS	0	1	1	213	1

0 = No Cracking
1 = Cracking Across Entire Width of Cladding

Reactions between the strip electrode and the slag produced small but beneficial reductions in carbon and iron contents in the cladding (Figure 6). However, the Si content of the cladding was always greater than that of the strip electrode particularly for the SAS process. Within each cladding layer, the chemical composition was uniformly distributed except at the interface between the Ni alloy cladding and the Class 1 steel base metal. A transition zone of 140 microns (0.006 inch) was needed for the composition to adjust from that of the base metal to that of the bulk cladding.

Oxygen Content of Cladding

The oxygen content of the cladding was found to be dependent upon the oxygen potential of the flux. Since the ESS flux contained approximately 80% calcium fluoride, its oxygen potential was very low compared to the SiO_2-rich flux used for SAS (Table II). As a result, the inclusion concentration and oxygen content of the cladding deposited by SAS was approximately three times that of the cladding deposited by ESS. Typical oxygen content of the ESS cladding of Ni Alloy 625 was 280 ppm while similar SAS cladding contained over 700 ppm.

Microstructure of Cladding

The cladding microstructures deposited by both ESS and SAS consisted of primary gamma matrix dendrites and interdendritic precipitates, which were mainly Nb-rich MC carbides and Laves phase, as shown in Figure 7a. In the cladding microstructure deposited by ESS, the post-weld stress relieving treatment at 604°C (1120°F) for two hours caused some precipitates to grow into a coarse irregularly-shaped morphology as shown in Figure 7b. In contrast to the relatively inclusion-free cladding deposited by ESS, the cladding deposited by SAS contained many inclusions introduced by slag reactions in addition to the large MC carbides and Laves phase precipitates, as shown in Figure 7(c) and (d) for as-welded and stress relieved conditions, respectively.

Related to the microstructures shown in Figure 7, the reduction of ductility was understandable due to the excessive inclusion content and coarseness of the interdendritic precipitates in cladding deposited by SAS. Examination of the tensile fracture surfaces of cladding deposited by SAS showed that the cracks preferred to propagate along the interdendritic spaces. However, for similar cladding deposited by ESS, the fracture exhibited a homogeneously distributed dimple structure. Therefore, the reduction of ductility in SAS was attributed to the excess quantities of oxide inclusions, Laves phase and MC carbides in the interdendritic areas. Nevertheless, cladding produced by both ESS and SAS passed the 22% ductility requirement (MIL-S-23284, Class 1 shafting) for side bend tests at room temperature in Table V.

In comparing the microstructures of ESS cladding deposited by Ni Alloy 625, Ni Alloy 625 with low Fe and Alloy 59, Ni Alloy 59 contained less than one third of the Laves phase observed in the other Ni cladding alloys as shown in Table VII. This may account for the superior solidification cracking resistance of Alloy 59.

Preheating Temperature Determination

Because of its high hardenability and carbon content, the shaft material must be preheated to avoid hydrogen-induced cold cracking. Although the preheating temperature of MIL-S-23284, Class 1 steel is specified in NAVSEA 0900-LP-o14-1010 for conventional welding operations (but not ESS), the effect of preheating temperature was investigated for the new ESS process using Ni-Alloy 625 filler metal. The microstructures of heat-affected zone of the Class 1 base metal (obtained by optical and transmission electron microscopy) has been summarized as a function of preheating temperature in Table VIII. From these results, totally safe welding conditions occur when the preheating temperature was equal to or greater than 204°C (400°F) since all of the martensite was in the tempered condition. However, preheating at 150°C

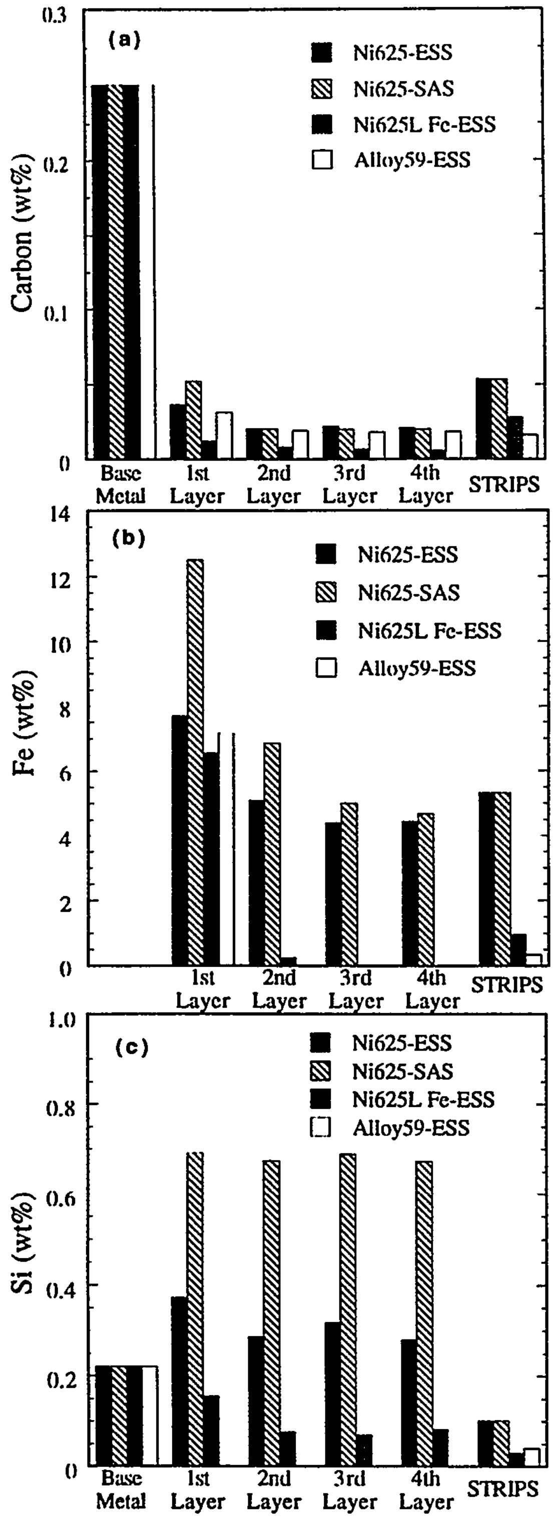

FIGURE 6. Composition of 1st Through 4th Layers of Cladding Deposited by ESS and SAS Using 30 X 0.5 mm Strip Electrodes: (a) Carbon, (b) Iron, and (C) Si.

TABLE VII. Relative Amounts of Leaves Phase in the Microstructure of Cladding Deposited by Electroslage Surfacing on MIL-S-23284, Class 1 Steel Using Ni Alloy strips

Strip Material	Relative Amount of Laves Phase (counts/ field)	Confidence (%)
ESS - Ni Alloy 625	477	98
ESS - Ni Alloy 625 Low Fe	162	99
ESS - Ni Alloy 59	54	98
GMAW Cladding* - Ni Alloy 625	512	97

* For comparison with conventional cladding by GMAW with wire electrodes.

(300°F) produced a microstructure that was predominately tempered martensite and bainite.

The Japanese Industrial Standard (JIS z 3158) known as the Y-Groove Cracking Test was also used to quatify preheating temperatures for the ESS process. Since the Y-Groove Cracking Test has been developed for wire welding systems, the Ni Alloy 625 wire and ESS flux were used (in the Y-Groove Cracking Test) to evaluate the cracking resistance of the cladding material. Y-Groove tests were conducted on 25 mm (1 inch) thick MIL-S-23284, Class 1 steel base metal using Ni Alloy 625 filler wire as well as MIL-loos-1 steel filler wire (matching the base metal strength), for reference. Y-Groove Cracking Tests were performed in the electroslag mode at different preheating temperatures including: room temperature, 94°C (200°F), 150°C (300°F), and 204°C (400°F).

Results showed that one out of three Y-Groove specimens welded with matching steel filler wire preheated to 94°C (200F) cracked in the HAZ. The Y-Groove test specimens welded at 300°F were crack-free. Cold cracks have been observed in the HAZ of test specimens of the Y-Groove Cracking restraint test of preheated at 94°C (200°F) but have never been detected on cladded shaft material at this preheating temperature. When Y-Groove Cracking Tests were conducted with Ni Alloy 625 wire, no cracking was observed at 94°C (200°F). It is

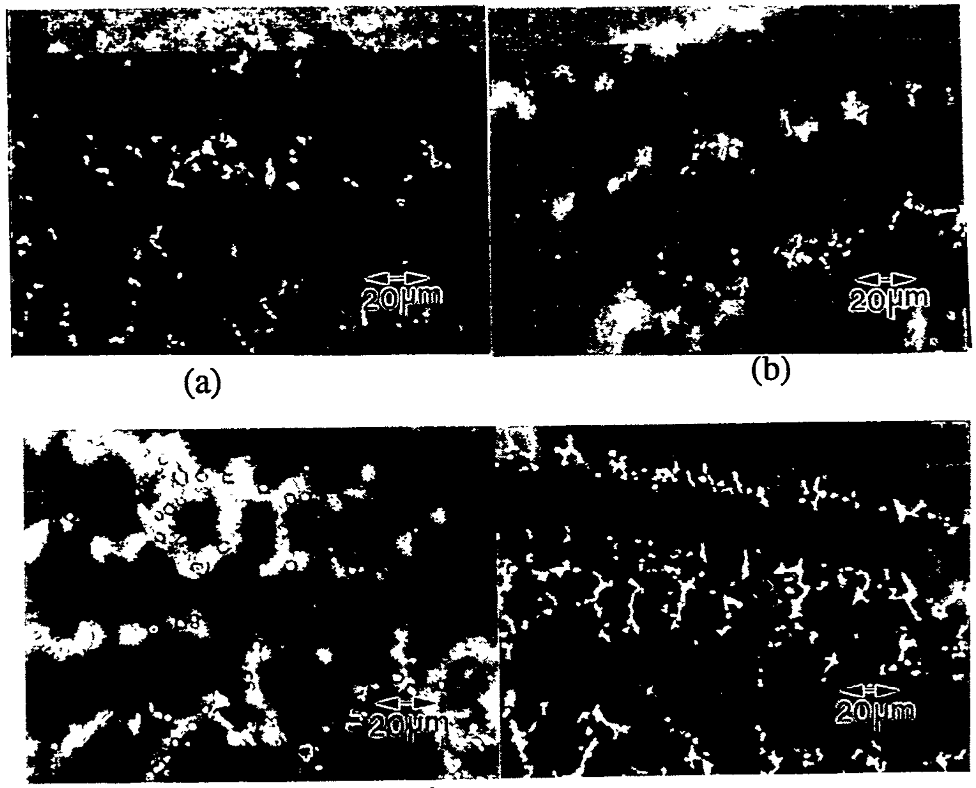

FIGURE 7. Microstructures of Cladding Deposited with Ni Alloy 625 by ESS and SAS: (a) ESS, As-welded, (b) ESS, after Stress Relief at 604°C (1120°F), (c) SAZ, As-weided, and (d) SAS, after Stress Relief at 604 C (1120°F). Precipitates are Laves and Nb-rich (MC Type) Carbides.

TABLE VIII. TEM Analyses of the Heat-Affected Zone of Cladded MIL-S-23284 Class 1 Steel

	Microstructure	
Preheat Temperature	ESS	SAS
As-cladded		
93°C (200°F)	Martensite + Bainite	Martensite + Bainite
150°C (300°F)	Martensite + Tempered Martensite + Bainite	
204°C (400°F)	Tempered Martensite + Bainite	
Post Weld Stress Relief at 604°C (1120°F)		
93°C (200°F)	Tempered Martensite + Bainite	Tempered Martensite + Bainite

believed that the high solubility of hydrogen in nickel and reduction in hydrogen diffusivity in nickel cladding significantly reduced solidification - cracking susceptibility. Thus, the required preheating temperature of 204°C (400°F) appears to be very safe.

In determining the amount of diffusible hydrogen in the cladding, Ni Alloy 625 was deposited in the electroslag mode on Class 1 steel plate per AWS B4.0 using the ESS flux. From Figure 8, the variable having the greatest effect on the amount of diffusible hydrogen was the flux baking temperature prior to cladding. A minimum baking or holding temperature of 93°C (200°F)is required to maintain control of diffusible hydrogen content. The heat input had no appreciable effect on the amount of diffusible hydrogen in the cladding (Figure 8). The use of Ni Alloy 625 filler metal significantly reduced the amount of diffusible hydrogen in the weld metal because of hydrogen's high solubility in Ni and the order of magnitude slower diffusion rate of hydrogen in face-centered cubic Ni. As a result, cladding with Ni alloys presents a diminished threat of hydrogen induced cold cracking particularly after post-weld stress relieving at 604°C (1120°F).

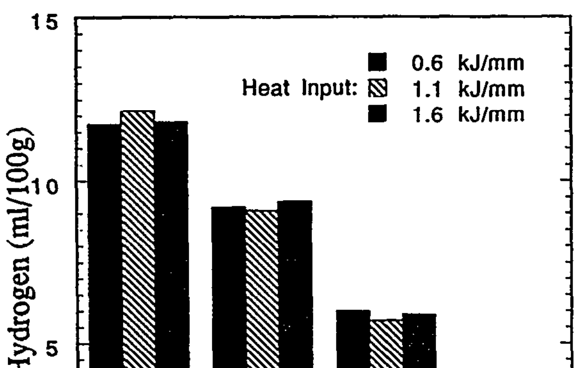

FIGURE 8. Diffusible Hydrogen Content of Steel and Ni Alloy 625 Cladding for Different Flux Baking Temperatures.

CONCLUSIONS

An investigation was conducted to determine the characteristics, properties and microstructure of cladding deposited on steel by ESS and SAS processes using Ni alloy strip electrodes. The following can be concluded:

1. ESS provides lower dilution, lower and more uniform penetration, and higher deposition rate than does SAS under the similar cladding conditions.

2. Cladding deposited with Ni Alloy 625 strip by ESS is less sensitive to solidification cracking than similar cladding deposited by SAS.

3. Oxygen content of cladding deposited by ESS is less than l/3 that of similar SAS cladding.

4. Microstructures of cladding deposited by ESS and SAS contain both MC carbides and Laves phase.

5. Cladding deposited with SAS is substantially higher in Si content compared to similar cladding by ESS.

6. In comparing ESS cladding deposited with Ni Alloy 625, Ni Alloy 625 low-Fe, and Ni Alloy 59, all strip electrodes produce nearly similar mechanical properties. Alloy 59 appears to be least sensitive to solidification cracking. Alloy 59 cladding contains the least amount of detrimental Laves phase due to its low Nb content.

7. Because Ni alloy cladding is deposited over MIL-S-23284, Class 1 steel, preheating temperatures as low as 150°C (300°F) are effective in preventing HAZ cracking.

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REFERENCES

1. G. Seidel and H.Hess, Investigation of the Electroslag Strip Cladding with Strip Electrodes, Schweissen Schneiden, Vol. 23(10), 1971.

2. S. Nakano, N. Nishiyama, T. Hiro and J. Tsuboi, Maglay Process Electra-Magnetic Controlled Overlay Welding Process with ESW, Kawasaki Steel Technical Report, No.2, March, 1981.

3. R. Killing, Influence of Welding Powder and Welding Parameters on the Welding Process in Electroslag Strip Cladding with Strip Electrodes, Schweissen Schneiden, Vo1.40(10), 1988.

4. S. Forsburg, Resistance Electroslag (RES) Surfacing, Welding Journal, Vol. 64, August, 1985.

5. R. Killing et al, Performance Characteristics of Electroslag Weld Cladding with Strip Electrodes, Schweissen Schneiden, Vo1.40, No.6, 1988.

6. A. Van Bemst and Ph. Dargent, Electroslag Cladding using Nickel Base Alloys, Metal Construction, Dee 1983.

7. U. Heubner, T. Hoffmann and G. Rudolph, Overlay Welding of Corrosion Resistant Nickel Superalloys, in "Weldability of Materials", R.A. Patterson and K.W. Mahin (eds.), ASM International, Materials Park, OH, 1990.

8. D.W. Yu and J-H. Devletian, Electroslag Surfacing: A Potential Process for Rebuilding and Restoration of Ship Components, Journal of Ship Production, Vol. 5(2), May 1989.

9. Y.K. Oh and J.H. Devletian, Electroslag Surfacing for Shipbuilding and Repair, Sea Technology, June 1990.

10. Y.K. Oh, J.H. Devletian and S.J. Chen, Low Dilution Electroslag cladding for Shipbuilding, Welding Journal, Vol. 69(8), 1990.

11. J-H. Devletian, A. Koch and E.N. Buckley, Unique Application Initiates the Introduction of Electroslag Cladding to U.S. Industry, Welding Journal, Vo1.71(1), January 1992.

12. Y.K. Oh and J.H. Devletian, Electroslag Strip Cladding of Stainless Steel with Metal Powder Additions, Welding Journal, Vol.71(1), January 1992.

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